GEWEX Cloud System Study
Working Group II - Cirrus Cloud Systems
1999 Report

1. Overview

The goal of WG2 is to stimulate progress in developing physically-based parameterizations of cirrus cloud processes for implementation in large-scale models used for climate simulation and numerical weather prediction (NWP). State-of-the-art general circulation models (GCMs) now explicitly predict the occurrence and amount of cloud ice in the atmosphere. Models such as the ECMWF model produce cloud ice (cirrus) in a qualitatively realistic fashion, both via large-scale ascent (dominant in winter hemisphere middle latitudes) and via detrainment from deep convective cloud systems (Jakob, 2000). However, there is little observational guidance in terms of the actual ice water budget of the atmosphere, especially at cold upper tropospheric levels where the radiative impact of clouds can be quite strong in the infrared spectral region. Thus, present GCM results show significant range, even for gross parameters such as the global mean ice water path (Rasch and Kristjansson, 1998). Two common (sub)parameterizations, the autoconversion rate for conversion of "pristine" ice crystals to larger and more rapidly falling ice crystals ("snow") and especially the account of the ice crystal sedimentation (fallout) process, enable GCM results to be "tuned" such that reasonable agreement with observed outgoing longwave radiation (OLR) budget (e.g., ERBE) is achieved. However, this "tuning" has considerable effect on the maintained ice content and cloudiness, and, thus, on the internal partition of cloud radiative forcing among the upper and lower troposphere and the Earth's surface with consequent effects on the general circulation, cloud formation, and climate. There are two paths by which the GCMs can be further constrained in this regard: 1) improved information on the ice budget of the upper troposphere as will likely result from future satellite missions such as CloudSat employing mm-wavelength radar and other ice water sensitive sensors, and 2) improved quantitative physical understanding of the processes of cirrus cloud formation, maintenance and dissipation. WG2 addresses the latter "process" path.

The fundamental approach of WG2 is to conduct systematic quantitative comparisons of cirrus cloud models, including cloud-resolving models (CRMs) and single column models (SCMs) as well as the (parcel) models underlying the treatment of cloud microphysical development in CRMs. The intent is to identify key processes and parameters leading to significant inter-model differences such that the investigators and measurements can be focused on resolving those differences. The ultimate goal is to validate the CRMs versus observations and then to use these models for studies supporting parameterization development. While WG2 is not presently engaged in GCM parameterization development or field experiments per sé, investigators deeply engaged in those activities are directly involved in WG2. Thus, WG2 strives to stimulate new approaches to parameterization though the intellectual exercise of understanding and improving the models which starts with the explicit comparison of present GCM parameterizations (SCMs) to the results from the more elaborate CRMs, as well as the intercomparison of the CRMs. The resulting identification of key process parameters and measurements required for validation and improvement of the CRMs also influences the direction and strategy for planned field experiments. The interaction of the modeling and observational communities around the focusing mechanism of the model comparison projects is extremely beneficial to both communities, as is also the case for the CRM and SCM/GCM communities.

Present SCMs resolve only a very crude representation of the operating cloud physics (microphysical, dynamical and radiative processes) and typically do not separate "cloud" processes from the issue of subgrid-scale variability and its causes. CRMs include a much fuller account of the cloud processes, including explicit size-resolved microphysical development and convective-scale dynamical processes. Moreover, CRMs provide a much closer match in scale and parameters to the observations provided by field experiments. Thus, they are better suited for comparison to field measurements and validation of the contained processes. Once validated in terms of cloud processes, CRMs can then be used to explicitly examine the subgrid-scale variability issue that is such a stumbling block at GCM scales, i.e., a highly useful separation of the problem into its fundamental component parts is achieved: cloud physics issues and subgrid-scale variability aspects. It should be noted that NWP models better resolve large-scale dynamical processes in comparison to "climate" GCMs and, thus, generally provide better representation of specific dynamical cloud forcing. NWP models therefore make an excellent testbed for parameterization in comparison to large-scale observations, such as satellite observations as seen in Miller et al. (1998). With smaller grid sizes in comparison to "climate" GCMs, the subgrid-scale issue might be viewed as correspondingly less difficult. However, parameterizations based on ensemble statistics may be invalidated as the contained sample becomes smaller.

1999 Workshop

WG2 conducted its second international workshop on modeling cirrus clouds in Geesthacht, Germany, during 19-21 May, 1999 (first workshop held in Williamsburg, USA, during 2-4 June, 1997.). The workshop was hosted by Markus Quante of GKSS under the sponsorship of Ehrhard Raschke. More than 25 scientists participated including CRM and SCM/GCM modelers and observationalists. The workshop was strongly focused on results of the first two WG2 projects. These projects are the Idealized Cirrus Model Comparison (ICMC) Project, developed and led by David Starr (NASA GSFC), and the Cirrus Parcel Model Comparison (CPMC) Project, developed and led by Ruei-Fong Lin (USRA at NASA GSFC). Numerous members of WG2 contributed to the development of these projects. Most notable were Phil Brown (UKMO) and Paul DeMott (CSU), respectively.

In addition to the projects (described in next section), the workshop provided a forum to stimulate involvement of the CRM community in GCM parameterization development including extended talks by Christian Jakob (ECMWF) on "Parameterizing Cirrus Clouds in GCMs" and by Martin Koehler (UCLA) on "Design of Empirically-based Prognostic Cloud Water Parameterization for GCMs" as well as a discussion of "Cirrus Parameterization in GCMs" led by David Randall (CSU). Talks were also given on the issues of cirrus contrails (Klaus Gierens, DLR) and of anvil clouds in the context of simulations of deep convective cloud systems (Wei-Kuo Tao, GSFC). There was a presentation by Jay Mace (U.Utah) on a possible WG2 project focused on existing well-observed cirrus cases at the Southern Great Plains (SGP) ARM site in Oklahoma, as well as future cloud experiments planned there. Starr briefly reviewed plans for the proposed FIRE CRYSTAL (Cirrus Regional Study of Tropical Anvils and Layers) experiments. Other relevant planned field activities were also briefly described.

Besides the above interactions and the findings of on-going WG2 projects, there were two other significant accomplishments at the workshop. WG2 adopted a steering committee composed initially of Starr, Brown, Mace and Lin to help facilitate development of WG2 activities. It was also agreed that the next logical step was to pursue an observed cirrus case study and that the SGP ARM data sets were the most appropriate available candidates. Mace (observations) and Starr (models) agreed to lead this effort that would begin in 2000.

2. Projects and Science Results

Idealized Cirrus Model Comparison Project

The ICMC Project involves the comparison of simulations of cirrus development and dissipation in two idealized baseline environments: a "warm" cirrus case and a "cold" cirrus case. In the "warm" cirrus case, cloud formation occurs in response to ice-supersaturated conditions in 1-km deep layer (-40°C) that is neutrally stratified with respect to ice pseudoadiabatic processes and bounded by stably stratified and less moist layers. The "cold" cirrus case is effectively identical except that the cloud forms in a higher colder layer (-60°C). The baseline simulations are made for nighttime conditions (infrared radiative transfer only) in the absence of vertical wind shear. Besides the initial forcing via ice supersaturation, continued ice generation is forced through an imposed cooling rate, continuously applied and corresponding to the effect of a uniform 3 cm s^{-1} uplift. Each simulation proceeds for four hours of simulated time after which the imposed cooling is turned off. The simulations then proceed for an additional two hours to enable assessment of the cloud dissipation phase of cloud life-cycle among the models. This is a critical issue in that cirrus clouds are commonly observed to be long-lasting. Simulations of variants of the baseline cases are also compared including no-radiation cases, stably-stratified cloud generating layer cases, and simulations where the fall speed of ice is fixed at a universal constant value (20 cm s^{-1} and 60 cm s^{-1}).

Results from 16 models (below) have been submitted for the ICMC Project. The models span a considerable range in terms of their design and heritage. The set includes single column models (SCMs) representing single-grid-point implementations of GCM models, and cloud-resolving models in two (2-D) and three (3-D) dimensions where the latter are commonly known as large eddy simulation (LES) models. Typical resolution in the CRMs is 100 meters, or better, in the horizontal and vertical dimensions. SCMs typically employ a vertical resolution of 500 meters. All models treat radiative processes though the radiative models and underlying relationships among cloud radiative and microphysical processes varies from model to model. The representation of cloud microphysics varies greatly among the models, from bulk treatments in SCMs and some CRMs, to fully explicit models accounting for microphysical development via integration of size-resolved growth

GCSS Working Group on Cirrus Cloud Systems
Participants in Idealized Cirrus Model Comparison Project

Institution	Investigator	Model	Microphysics
GSFC	R.F. Lin	2-D	bin
PSU	M.Boehm	2-D (Lin)	bin
ARC	E.Jensen	2-D, 3-D	bin
U.Utah	V.Khvorostyanov	2-D	bin
UKMO	P.Brown	2-D, 3-D	bulk
DLR	K.Gierens	2-D	bulk
CIRES	E.Girard	2-D	bulk
GFDL	M.Koehler	2-D	bulk
GSFC	D.Starr	2-D	bulk
CSU	A.Benedetti	2-D, RAMS	bulk
LOA	V.Giraud	2-D	bulk
FRSGC	K.Maruyama	2-D, GESIMA	bulk
GSFC	Y.Wang/W.K.Tao	2-D , GCEM	bulk
ECMWF	C.Jakob	SCM	bulk
CCCMA	M.Montero	SCM	bulk
UKMO	D.Wilson	SCM	bulk

equations. The latter include explicit account of the local aerosol population and nucleation processes with a theoretically-based treatment of homogeneous nucleation reflecting laboratory measurements, and an empirical treatment of heterogeneous nucleation. Some of the CRMs were explicitly designed as cirrus cloud models while others were originally developed for and applied to other cloud types such as deep convective cloud systems and boundary layer clouds ("heritage" models). Overall, the set of CRMs represents the vast majority of models presently being actively developed and applied for cirrus cloud research worldwide.

Analysis of ICMC Project results is on-going and definitive statements of findings may be somewhat premature. Based on the analysis and discussions of the model results at the WG2 Workshop in May 1999, it was concluded that a second iteration was needed in definition of the project and that the simulations would be re-done. This conclusion was reached in response to unforeseen difficulties including: a) unacceptable instabilities, found predominantly in the "heritage" model results, associated with improper implementation of the specified boundary conditions, and b) an undesired "sliding-layers" behavior that was widespread among the models. The latter was associated with model adjustment to the occurrence of strong dynamical reaction to the specification of an unstable cloud generating layer. After the workshop, a significant effort was made to further test selected models, boundary conditions, and initial conditions in order to understand the problems. These efforts were largely successful and led to a new better designed project and significantly improved results in terms of elimination or reduction of obvious problems. In addition, the re-designed project adopted different protocols for examining the dissipation phase of cloud life cycle. Some variants of the baseline cases were eliminated and replaced with experiments focused on understanding some of the very significant discrepancies that were evident in the first round of simulations.

The initial round revealed a strong tendency for a partition of model results according to the general class of microphysical formulation, i.e., bulk treatments versus explicit size-resolved (bin) treatments, as indicated below.

Bulk Microphysics	Bin Microphysics
Less Ice Water	More Ice Water
Less Energetic	More Energetic
Greater Vice	Smaller Vice
Static Cloud Top	Upward Propagation of Cloud Top

The differences were substantial and consistent with significant differences in the ice crystal size distribution present. In effect, the bin models had significantly smaller ice crystals, overall, which had substantial consequences in most all aspects of the simulation. Not only were there substantial differences in horizontally-averaged, vertically-integrated ice water path (IWP), but *the vertical distribution of ice water was also characteristically different,* tending to be peaked toward cloud top in the bin model simulations versus the occurrence of a strong ice water content (IWC) peak low in the cloud for the bulk models. In essence, the bin models behaved in a manner suggestive of altocumulus or stratocumulus clouds. Thus, the re-designed project included simulations where the ice water fall speed (V_{ice}) was set to a universal constant values of 20 cm s^{-1} and 60 cm s^{-1}. The notion was to "trick" the models of one class into behaving like the models of the other class where small values of V_{ice} were associated with the bin model simulations and larger values with the bulk model simulations. To clarify, V_{ice} is the effective ice water fall speed corresponding to the vertical flux of ice water normalized by the ice water content where the effect of local vertical air motions are removed. It is not a simple constant or parametric function in the bin models, but can be quite variable in time and space. Significant diagnostics were required to evaluate the statistics of V_{ice}.

While analysis of the ICMC Project results is presently proceeding, it can be stated that the re-designed project was very successful. Many of the serious difficulties found in the first iteration were eliminated. The above conclusions about bin versus bulk models, while tempered somewhat for the warm cirrus cases, remained essentially the same for the cold cirrus cases (Figure 1). The spread found in IWP between the models, e.g., at 240 minutes, is at first discouraging. Conversely, however, this indicates that dramatic measurable improvements may be achieved. Moreover, present observational capabilities should

IWP -- C/WNir

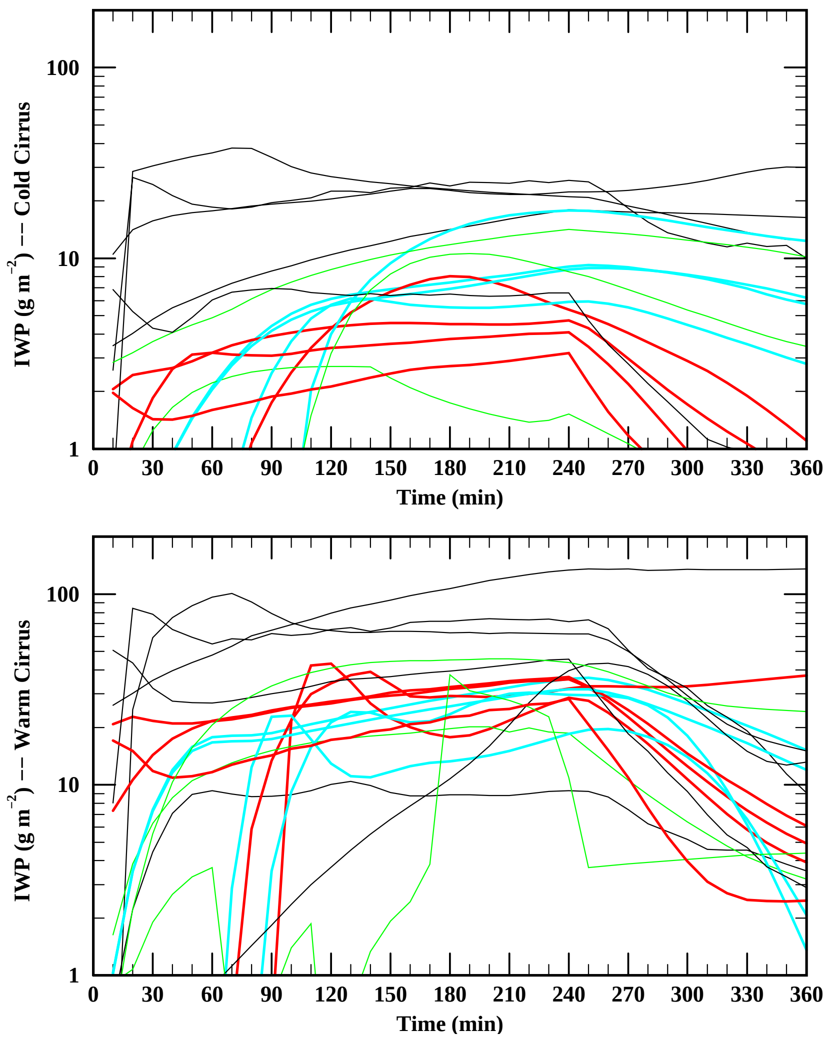

Figure 1: Time series of vertically-integrated ice water path (g m^{-2}) from cirrus cloud simulations by models participating in the GCSS WG2 Idealized Cirrus Model Comparison Project. These baseline simulations correspond to nighttime (infrared radiation only) "warm" cirrus (lower panel) and "cold" cirrus (upper panel) cases with cloud top at about –47°C and –66°C, respectively, subject to continuous cooling representing a 3 cm s^{-1} uplift over a 4-hour time span followed by a 2-hour dissipation stage. Shown are results from cloud resolving models with "bin" microphysics (cyan), CRMs with bulk microphysics (red), single column models (green), and CRMs with heritage in study of deep convection or boundary layer clouds (thin black). Notice the large range of values produced by these state-of-the-art models after 4 hours of simulation, and that a) bin and bulk CRM results tend to separately cluster, b) SCMs results span the range of CRM results, c) heritage models exhibit larger scatter and d) larger spread is found for the "cold" cirrus case where the dissipation phase is notably different between the bin and bulk models and where observations are especially sparse and uncertain.

permit differences of this magnitude to be effectively resolved through a robust effort at model validation versus observations, i.e., case studies or other relevant focused data collection/analyses as planned by WG2.

The experiments using constant specified values of ice water fall speed for all ice crystals and ice crystal populations were also quite successful. Bin models were "tricked" into behaving like the bulk models and vice versa. Thus, it is concluded that it is indeed the size distribution differences that cause the partition of results according to the manner in which microphysical process are represented. Moreover, these results suggest that validation of cirrus cloud models should strongly consider more detailed information than simply IWP. Specifically, both the vertical structure of cloud ice water content and the intensity of internal cloud circulations (cloud-scale vertical air motions) provide strong correlated indicators of cloud microphysical makeup, i.e., ice crystal size distribution. With multiple measures, it may be possible to overcome the inherent uncertainties associated with any particular measure such as IWC the accuracy of which is typically sensitive to the size distribution (and thus height) for each available sensing approach, i.e., mm-radar and *in-situ* probes.

Cirrus Parcel Model Comparison Project

The CPMC Project, with five participating models, involves a comparison of detailed calculations of microphysical development in the limited framework of a parcel model. These models are the basis for the somewhat simplified implementations used for size-resolved treatment of microphysical development in the CRMs of the WG2 ICMC Project. Calculations are made for various rates of imposed uplift (4, 20, and 100 cm s^{-1}), as might occur locally in generating cells or via mesoscale or large-scale lifting, for conditions corresponding to the same "warm" and "cold" cirrus cases used for the ICMC Project. These Lagrangian simulations assume a closed system with no exchange of energy, vapor or ice between the parcel and its environment. The first phase of this project considered model response to an initial humidity of 100% with respect to ice with a specified initial distribution of sulfuric acid aerosols (200 cm^{-3}) as input to the homogeneous nucleation process. Two sets of calculations were initially done. In the first, no additional constraints were placed on the models such that the "native" treatments of homogeneous and heterogeneous nucleation processes operated. In the second set, heterogeneous nucleation processes were turned off, such that homogeneous nucleation was the only available nucleation process. Additional simulations for selected conditions were also made subject to additional constraints on the treatment of the homogeneous nucleation process (selection of internal model parameters) so as to further investigate discrepancies that were found. The participating models are briefly summarized in the following table.

GCSS Working Group on Cirrus Cloud Systems
Participants in Cirrus Parcel Model Comparison Project

Institution	Investigator	Ice Bins/Method	Homogeneous	Heterogeneous
UK-MRF	R.Cotton	20 discrete Lagrangian	T_{eff} $\lambda = 1.5$	S_i dependent deposition nucleation
CSU	P.DeMott	32 continuous Lagrangian	T_{eff} $\lambda = 1.5$	immersion freezing nucleation
ARC	E.Jensen	60 continuous Eulerian	"classical" theory	
GSFC	R.-F.Lin	25 continuous Lagrangian	T_{eff} $\lambda = 1.0$	S_i dependent deposition nucleation
U.Utah	K.Sassen	particle tracing Lagrangian	T_{eff} $\lambda = 1.7$	T_{eff} dependent modified Fletcher nucleation

Discrete versus continuous, and Lagrangian versus Eulerian, refer to the manner in which the integration is performed in particle-size space. In the Lagrangian method for example, the growth of particles in a particular size bin is evaluated and changes the particle size (discrete), or sizes (continuous), associated with that bin, while particles move from one fixed-size bin to another as they grow in the Eulerian approach. In the effective freezing temperature approach, T_{eff} is used to directly link the nucleation rate in solution droplets to that in pure water droplets from "classical" theory, where λ is an internal parameter used for this adjustment. Conversely, the homogeneous nucleation rate of ice in solution droplets is evaluated directly from classical theory in the "classical" approach. Note that the Lin and Jensen parcel models have been incorporated into multi-dimensional CRMs participating in the WG2 ICMC Project described above.

In the Phase 1 comparisons, broad qualitative agreement was found in the results for the homogeneous-nucleation-only (*hno*) simulations, but significant quantitative discrepancies were also found (Figure 2). Discrepancies remained even after initial problems with the specification of saturation vapor pressure and model-dependent details of the evolution of aerosol size distribution in ascending parcels were addressed. Differences in the number of nucleated ice crystals were as large as a factor of 10. The spread was slightly greater in the "cold" cirrus cases. An effort was made to bring the models into agreement, employing common physical parameters such as λ, but the discrepancies between the "classical theory" model and the other models persisted over substantial portions of the parameter space and are attributed to the fundamental difference in treatment of the nucleation process. Specification of common internal model parameters brought about fairly close agreement in all the T_{eff} models, except one. In this case, the differences appear to be attributable to differences in details of model design. In the T_{eff} models, the results are very sensitive to what happens over a very short time interval as nucleation initiates and then rapidly shuts off. This yields a fairly strong sensitivity to microphysical parameters, like the growth rate of a given ice crystal, and numerical procedures.

For the next phase of the CPMC Project, sensitivity (*hno*) to the aerosol size distribution is being examined, i.e., number density, mode radius and width of the distribution.

The results for the homogeneous-and-heterogeneous nucleation (*hah*) simulations showed somewhat greater divergence. Unlike in the *hno* comparisons, however, the qualitative behavior of the models differed where the dependence of ice crystal number density on updraft velocity varied significantly from model to model, i.e., the curves cross significantly. The divergence was particularly great at slow to moderate updraft speeds where the homogeneous nucleation process was typically not activated. The approaches used to treat heterogeneous nucleation vary significantly from model to model. In some models, these are empirical parameterizations that operate in the absence of an explicitly specified aerosol population. Without adequate laboratory or field measurements, it is difficult to proceed further with the consideration of heterogeneous nucleation process.

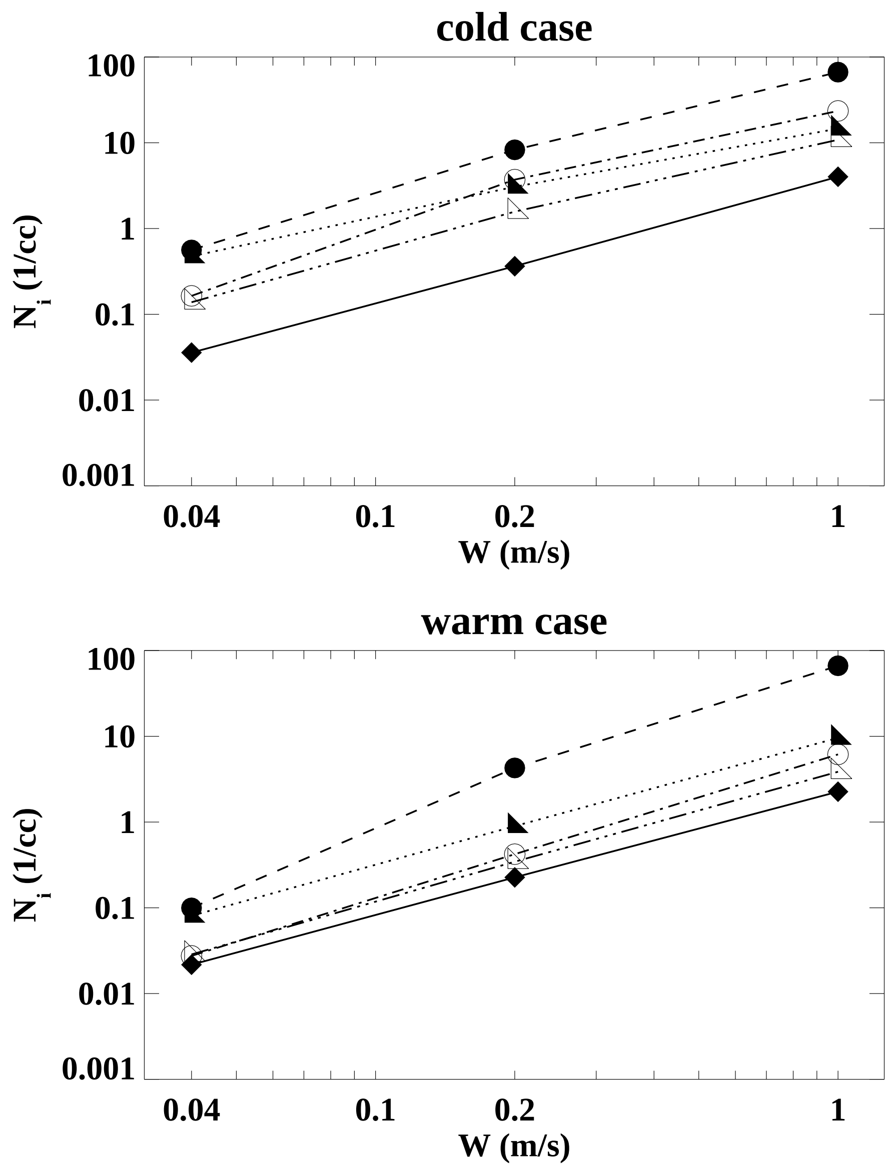

Figure 2: Number of ice crystals (N_i) nucleated in simulations of ascending closed air parcels by models participating in the GCSS WG2 Cirrus Parcel Model Comparison Project, as a function of the imposed rate of uplift (W) from an initial temperature of -60°C (cold) and -40°C (warm). These simulations include only homogeneous nucleation (*hno*) and were performed with "native" model parameters. Better agreement is found between most of the T_{eff} models when common physical parameters are used.

3. Accomplishments in 1999

- *Formation of an Effective International Cirrus Cloud Systems Working Group*

  WG2 now involves the vast majority of research groups concerned with the details of modeling cirrus clouds, with active participation by large-scale modelers and key researchers concerned with measurements of cirrus clouds. International workshops were held in 1997 and 1999, each involving more than 25 scientists. Another workshop is planned for summer of 2000. WG2 maintains a homepage through which the project protocols and results are disseminated (http://eos913c.gsfc.nasa.gov/gcss_wg2/).

- *Conduct of Cirrus Model Comparison Projects*

  Two projects are ongoing: the Idealized Cirrus Model Comparison Project involving CRMs and SCMs (results from 16 models) and the Cirrus Parcel Model Comparison Project concerning details of nucleation and microphysical development in cirrus (results from 5 models). A third project involving a simulations of a well-observed case from an intensive observing period (IOP) at the Atmospheric Measurements Program (ARM Southern Great Plains (SGP) site is in its initial phase (analysis and case selection).

- *Quantitative Assessment of Results from of State-of-the-Art Cirrus Cloud Models*

  Substantial disparities (and congruities) between simulations using state-of-the-art cirrus cloud models have been documented. The differences that have been found between CRMs exceed what might have been expected based on the literature. The SCMs exhibit a similar range. It is concluded that these models have not been quantitatively validated versus observations with adequate rigor.

- *Identification of Key Issues and Field Measurements*

  Early results from the WG2 projects indicate that a key source of discrepancy among models is centered on the ice crystal size distributions that are simulated with bin models producing smaller crystal sizes overall than found in bulk models. This discrepancy is manifest in many ways including the vertical flux of ice water (effective ice water fall speed), assessment of cloud radiative properties, and even in the most gross measures such as average vertically-integrated ice water path. These results have served to focus measurement and analysis efforts on new and particularly pertinent data sets, such as those produced by sensitive Doppler radars operating at mm wavelengths for vertical flux of ice water. The comparison results also indicate that significant differences should be found in the structure of ice water, especially the vertical distribution, and in the dynamical intensity associated with internal cloud circulations based on the assessment of ice crystal size distribution. While much effort has been (and will be) expended on measurement of the IWC profile and IWP, there remain fundamental uncertainties associated with the various measurements approaches and algorithms that are size-distribution (height) dependent. The identification of additional correlated measures for discriminating the dominant cloud processes, and thereby size distribution, may allow a more definitive resolution of this issue.

- *Identification of Key Issues and Laboratory Measurements*

While some significant issues concerning the account of homogeneous nucleation have been identified, and resolved in some instances, findings indicate that heterogeneous nucleation remains a difficult process to treat. The requisite laboratory measurements of homogeneous nucleation in solution droplets, though improving, provide inadequate guidance in these regards. It is likely that heterogeneous nucleation is an important process in determining the ice crystal size distribution when convective or mechanical instability is absent, or of secondary importance, and the forcing to cloud formation derives predominantly from weak to moderate large-scale ascent (cooling). New field measurements of the ambient aerosol population, and especially ice nuclei, will provide some guidance, but it is clear that focused laboratory studies on the activity of heterogeneous agents are required. Models allowing simultaneous consideration of multiple, size-dependent, particle compositions are also desired.

It should be noted that the CPMC Project directly addresses the primary source of dispersion found in the present results of the ICMC Project, i.e., development of ice crystal size distribution.

- *Integration of Modeling and Observational Communities - Impact on Field Experiments*

  WG2 (and the findings of its projects) is presently having a significant impact on the design and conduct of field experiments concerning cirrus clouds. This includes the ARM Spring 2000 Cloud IOP and the CRYSTAL-FACE (Cirrus Regional Study of Tropical Anvils and Layers - Florida Area Cirrus Experiment) planned for 2001 under the FIRE Program. WG2 is becoming fully integrated into the planning of these programs whereby the observational strategy reflects WG2 issues and applications and the acquired data will, hopefully, be optimized for use in future model comparison/ validation activities of WG2. In this way, the benefit of these observational programs will be more rapidly expanded to a broad international community.

In addition, members of WG2 contributed various chapters to a review book (in press by Oxford University Press) on the present state of knowledge about cirrus cloud systems that resulted from the Cirrus-98 Special Topical Session at the Optical Society of America 1998 Fall meeting.

4. Plans and Prospects

In 2000, WG2 will:

- complete analysis and publish results of the Idealized Cirrus Cloud Model Comparison Project (analysis well underway)
- publish results Phase 1 of the Cirrus Parcel Model Comparison Project (draft completed),
- complete analysis and publish results of Phase 2 of the Cirrus Parcel Model Comparison Project (analysis underway),
- develop a case study model comparison project based on one or more cases observed during IOPs at the ARM SGP site (case selection in progress),
- conduct a third cirrus modeling workshop in summer 2000,

- develop closer linkage to WG3 activities via conduct of the planned workshop jointly with WG3, and
- strive to develop closer linkage with WG4 with the aim of laying the groundwork for a unified deep convection/anvil cirrus case study.

In addition, further simulations and analysis may be designed and carried out to follow on the ICMC and CPMC Projects in order to pursue/resolve issues that arise and take these projects to the next level of sophistication/applicability. Specifically, consideration of the effects of solar absorption and vertical wind shear would be the next steps for the ICMC project while consideration of the effects of size-dependent aerosol composition and heterogeneous nucleation represent the next steps for the CPMC Project.

Moreover, WG2 will seek to influence the design of planned field experiments, specifically the ARM Spring 2000 Cloud IOP and CRYSTAL-FACE in 2001 to better address critical needs for measurements identified through WG2 projects.

In the long term, WG2 will complete (in 2000/2001) the presently planned case study and will likely expand this activity (in 2001/2002) to include one or more cases from the ARM Spring 2000 Cloud IOP. It is possible that a case involving convective generation of cirrus over the ARM SGP site may also be considered, either in association with WG4 or from past IOPs - a case from May 1997 is being examined. However, in addition to extensive surface and satellite based remote sensing observations and adequate sounding data, it is critical that such cases have strong *in-situ* aircraft support to be optimally useful in addressing the science issues. It is hoped that collaborations between WG2 and WG3 will develop and grow, where a strong involvement of satellite community is seen as essential to this development. However, the central long-term objective of WG2 is to consider convectively generated cirrus cloud systems, especially tropical systems. This will require close cooperation, possibly a merger, with WG4 and will take advantage of opportunities for pertinent data from CRYSTAL-FACE in 2001 as well as for other cases considered by WG4, though the lack of *in-situ* observations may force a focus on FIRE-CRYSTAL. It is hoped that such a joint WG2-WG4 activity can be initiated before 2002.

Philosophically, WG2 will continue to operate in the "traditional" GCSS mode for the next couple of years, i.e., large-group activities. However, an evolution to a more disperse mode is envisioned for 2002 and beyond where individual modelers or small subgroups, operating in collaboration with field and/or satellite observationalists, or parameterization developers, address specific issues or needs deemed essential to progress in understanding cirrus clouds and their representation in GCMs. For example, this could entail assessment of ensemble simulations, simulation sets in support of parameterization development or analysis of satellite data in conjunction with assimilated analyses, or investigation of specific cloud processes.

Future Prospects

The cirrus cloud modeling community has rapidly grown in the last few years. Many of the modelers are young scientists, becoming involved in WG2 during the course of their Ph.D. dissertation research in some instances. For the most part, this research was supported in a "bootstrap" mode. The community has nevertheless reached a critical mass that was heretofore missing. To continue the progress of WG2 and related research toward the goals of improved treatment of cirrus clouds in large-scale models and thereby improved understanding of the climate system at an expeditious pace, it will be essential for these young scientists to remain focused on cirrus cloud research. This requires a stable source of funding. While there have been some notable developments, such as the recent provision of some direct support for WG2 activities from the U.S. DoE ARM Program, it can also be said that there are no national programs dedicated to supporting cirrus cloud modeling. The institutional approach adopted by the UKMO is encouraging, i.e., active research at many levels (CRM, SCM, observations) with strong participation in WG2. However, this is not evident in the USA or elsewhere. The WG2 Chairman's view is that many of these promising young researchers will soon drift away from cirrus cloud modeling. There are already signs of this. Time is needed for the scientific maturation requisite for significant advancement in this area. It is recommended that the GEWEX SSG address this "institutional" issue in a meaningful manner. Continued reliance on the bootstrap mode, tied to graduate education, without substantive programmatic follow-up (funding, institutional commitment and jobs) will condemn us to this two-steps-forward and one-step-backward path and greatly delay progress.

Submitted respectfully,

David O'C. Starr
Chairman, GCSS WG2

REFERENCES

Jakob, C., 2000: Ice clouds in Numerical Weather Prediction models - Progress, Problems, and Prospects. Lynch, D. (ed.) "Cirrus", Oxford University Press, in press.

Miller, S.D., G.L. Stephens and A.C.M. Beljaars, 1998: A validation survey of the ECMWF prognostic cloud scheme using LITE. Geophys. Res. Lett., in press.

Rasch, P.J., and J.E. Kristjansson, 1998: A comparison of the CCM3 model climate using diagnosed and predicted condensate parameterizations. *J. Climate*, in press.